Degradable Airline Scheduling

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outline

- Degradable airline scheduling
  - Objectives
  - Motivation
- Modeling approaches
- Solution approaches
- Results
- Conclusion and further research

problems

- Bad weather reduces airport capacity
- Airlines have to cancel or delay some flights
- Delay propagates through out the network
- Airlines have to reschedule crew/aircraft and re-accommodate passengers
- Passengers are not satisfied
  - They are delayed
  - All passengers are delayed equally regardless of fare class

proposed solution

- Degradable airline schedule
  - Airline schedule that is partitioned into several smaller and independent schedules (layers)
- Priorities for each layer has a priority that is based on revenue (i.e. group high revenue flights together)

objectives and motivations

- To develop an airline schedule that:
  – is robust, i.e. delay propagation is isolated in a part of the schedule and does not impact the entire schedule
  – provides airline with a delay/cancellation policy
  – has various levels of importance for each flight so that passengers can know the priorities of flights before they buy tickets, thus improves customers satisfaction by giving passengers an accurate expectation of the level of service

outline

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- Modeling approaches
  - IP formulations
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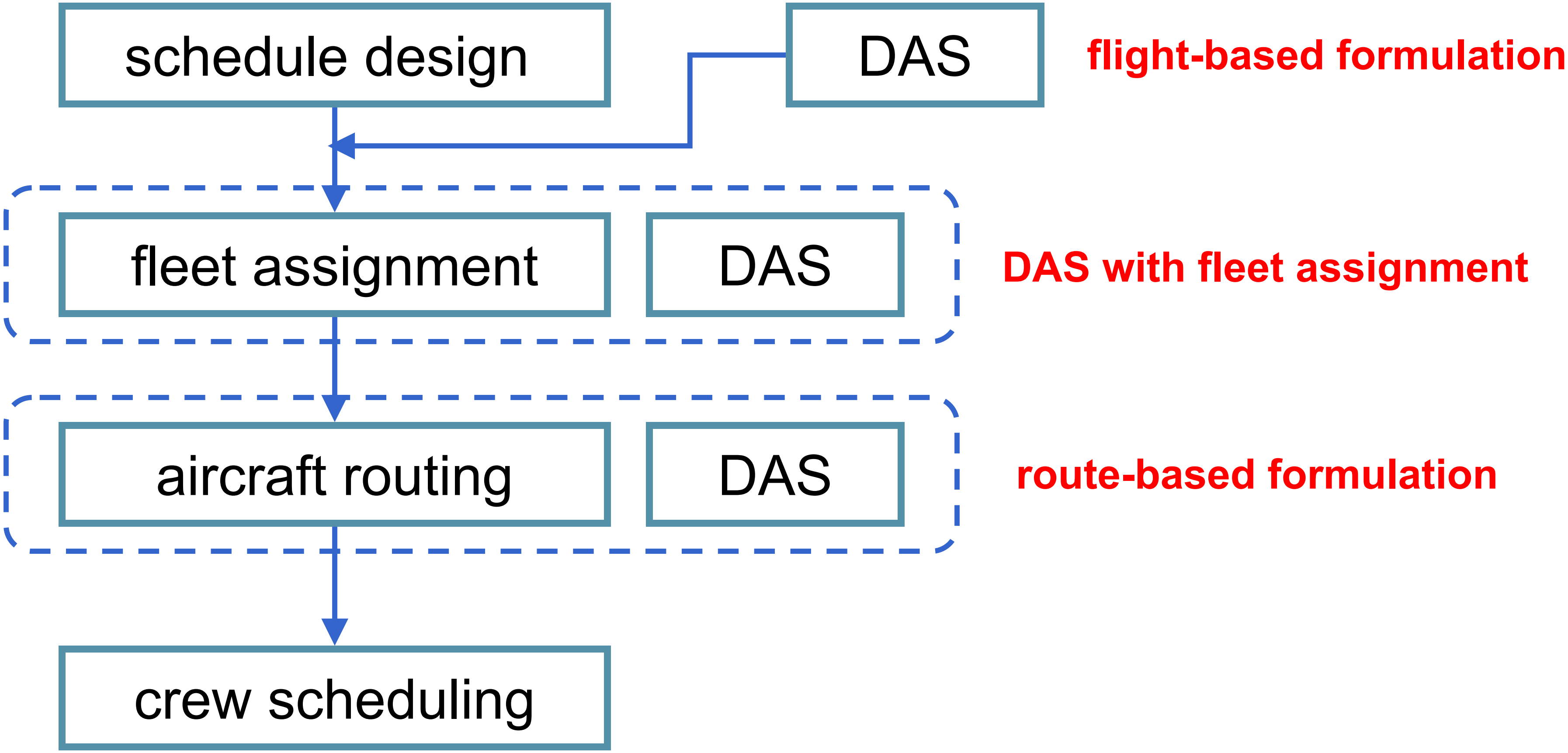
airline schedule planning process



IP model

- Revenue is “protected” if all flight legs of an itinerary are in a “protected” layer.
- All itineraries cannot be in the desired layer.

- IP model finds a feasible routing that maximizes the total protected revenue.

- We have 2 layers.
  - Layer 1: protected layer 60%
  - Layer 2: 40%

model stats

- 1,134 flight legs
- 274 aircraft
- 1,744 itineraries (8% of total)
  - Single flight leg: 1,130
  - 2 flight legs: 613
  - 3 flight legs: 1
- 53,091 passengers (80% of total)
- $10,839,340 revenue (84% of total)

notation

- Indices
  - r route
  - f itinerary
  - ij flight
  - k layer ($k=1 \ldots K$)
  - γ_{ij}^f 1 if flight ij is in itinerary f, 0 otherwise
- Decision variables
  - y_r^k 1 if route r is in layer k, 0 otherwise
  - z_f^k 1 if itinerary f is in layer k, 0 otherwise
  - x_{ij}^k 1 if flight ij is in layer k, 0 otherwise
- Parameters
  - v_f^k revenue for itinerary f is placed in layer k
  - C_h capacity at hub h in bad weather
  - S^k fraction of layer k
  - a_r number of flights in route r
  - a_r^h number of flights departing at hub h in route r
  - ACN number of aircraft

flight-based formulation

$$\max \sum_{f,k} v_f^k z_f^k$$

$$\text{s.t.} \sum_{ij \in F} x_{ij}^k \le S^k \qquad \forall k < K$$ → number of flights in each layer must be proportional

$$\sum_{k} x_{ij}^k = 1 \qquad \forall ij \in F$$ → all flights must be covered exactly once

$$\sum_{j} x_{ij}^k - \sum_{j} x_{ji}^k = 0 \quad \forall i \in N, k$$ → flow balance constraint

$$\sum_{\substack{ij \in h \\ k=1}} x_{ij}^k \le C_h \qquad \forall h \in H$$ → number of operations in protected layers must not exceed the airport capacity

$$\sum_{ij \in ON, k} x_{ij}^k \le ACN$$ → number of aircraft should remain the same

$$\boxed{\begin{array}{ll} z_f^k \ge x_{ij}^k \gamma_{ij}^f & \forall f, ij \in F, k \\ z_f^k \ge z_f^{k+1} & \forall f, k > 1 \end{array}}$$ → identify layer for itinerary

$$x \in \{0,1\}, z \in \{0,1\}$$

route-based formulation

$$\max \sum_{f,k} v_f^k z_f^k$$

$$\text{s.t.} \sum_{r} a_r y_r^k \le S^k \qquad \forall k$$

number of flights in each layer must be proportional

$$\sum_{k,r \ni ij} y_r^k = 1 \qquad \forall ij \in F$$

all flights must be covered exactly once

$$\sum_{\substack{r \ni h \\ k=1}} a_r^h y_r^k \le C_h \qquad \forall h \in H$$

number of operations in first two layers must not exceed the airport capacity

$$\sum_{r,k} y_r^k \le ACN$$

number of aircraft should remain the same

$$\boxed{\begin{aligned} z_f^k &\ge \sum_{r \ni ij} y_r^k \gamma_{ij}^f \qquad \forall f, ij \in F, k \\ z_f^k &\ge z_f^{k+1} \qquad \forall f, k \end{aligned}}$$

identify layer for itinerary

$$y \in \{0,1\}, z \in \{0,1\}$$

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- Degradable airline scheduling
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- Solution approaches
  - Greedy-type heuristics
  - Pair-wise swapping search
  - Tabu search
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greedy-type heuristics

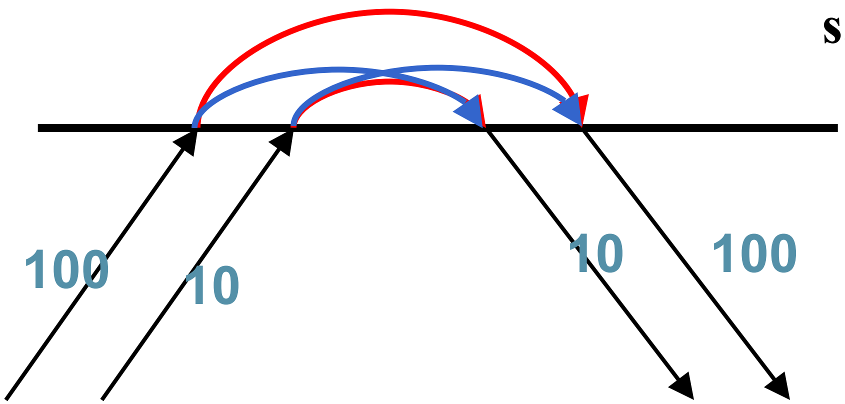
STEP 0: Fix connections for non-hub to non-hub flights

STEP 1: Pair flight segments at spoke airports using the revenue paring with aircraft utilization heuristic

STEP 2: Combine paired flight segments from step 1 at hub airports using the revenue paring with aircraft utilization heuristic

STEP 3: Partition very long routes into several shorter routes

revenue pairing with A/C utilization



value for each flight

$$\max \sum_{ij} c_i c_j x_{ij}$$

$$\text{s.t.} \quad \sum_i x_{ij} = 1 \qquad \forall j$$

$$\sum_j x_{ij} = 1 \qquad \forall i$$

cover constraint

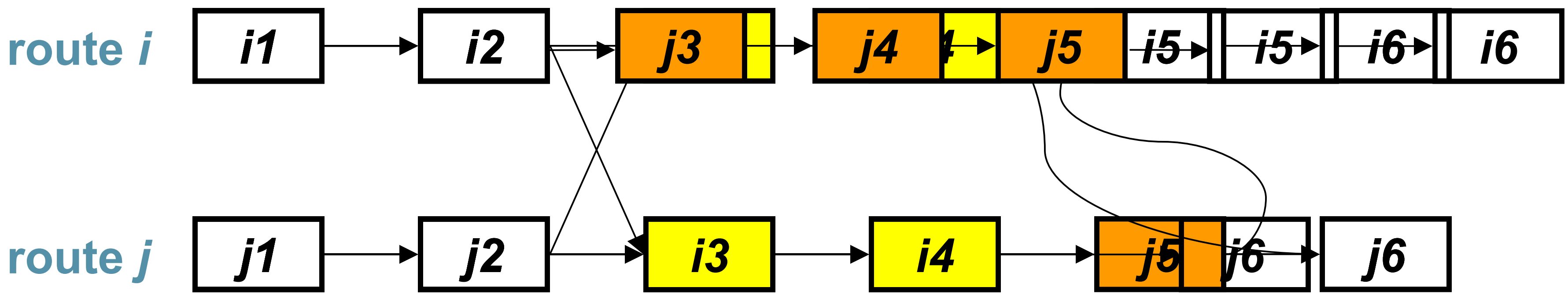
$$\sum_{ij} t_{ij} x_{ij} \le T$$

a/c utilization

$$x_{ij} \in \{0,1\} \qquad \forall ij$$

connection variable
1 = i is connected to j
0 = otherwise

pair-wise swapping search



- Check swapping feasibility
- Check constraints satisfaction
- Check objective function improvement
  – Assume revenue is protected proportionally to the number of flight legs in the protected layer
- Swap

tabu search

STEP 0: start with initial solution x^* from revenue paring heuristics

WHILE(number of iteration is less than N)

STEP 1: Pair-wise swapping search. If $f(x) > f(x^*)$, $x^* \leftarrow x$

STEP 2: Update Tabu list

- If a pair was in a tabu list for *Y* iterations, remove it from the tabu list
- Set *X* pairs which were swapped in the search in the tabu list

- Tabu search is sensitive to its parameters *X, Y, N*
- State-of-art decision for *X, Y, N*

IP objective function value

Flight-based Formulation	8,667,632
Tabu search	8,123,060
Pair-wise swapping search	8,102,680
Revenue pairing heuristics	7,655,430
Current routing	6,492,895

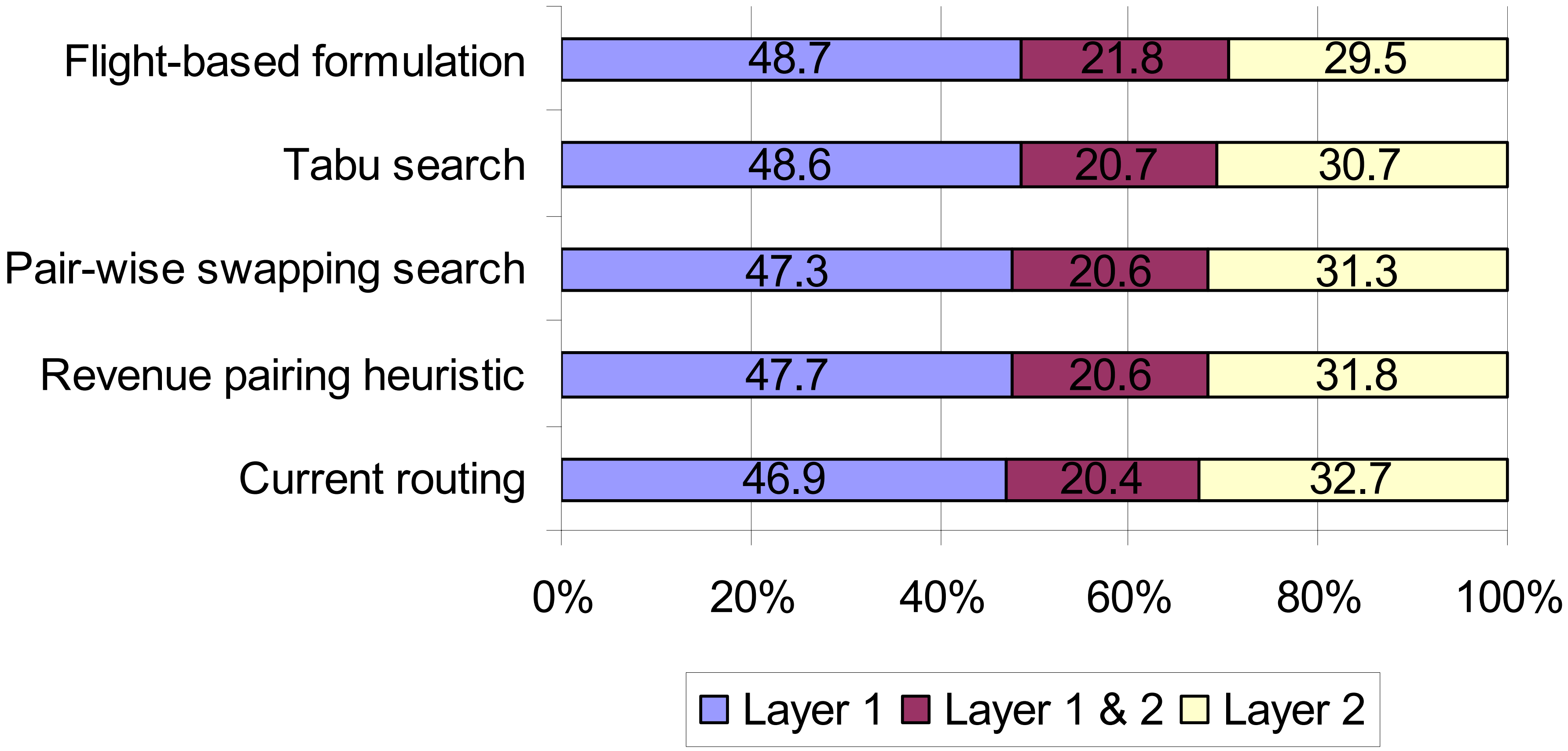
upper bound for route-based DAS

lower bound for route-based DAS

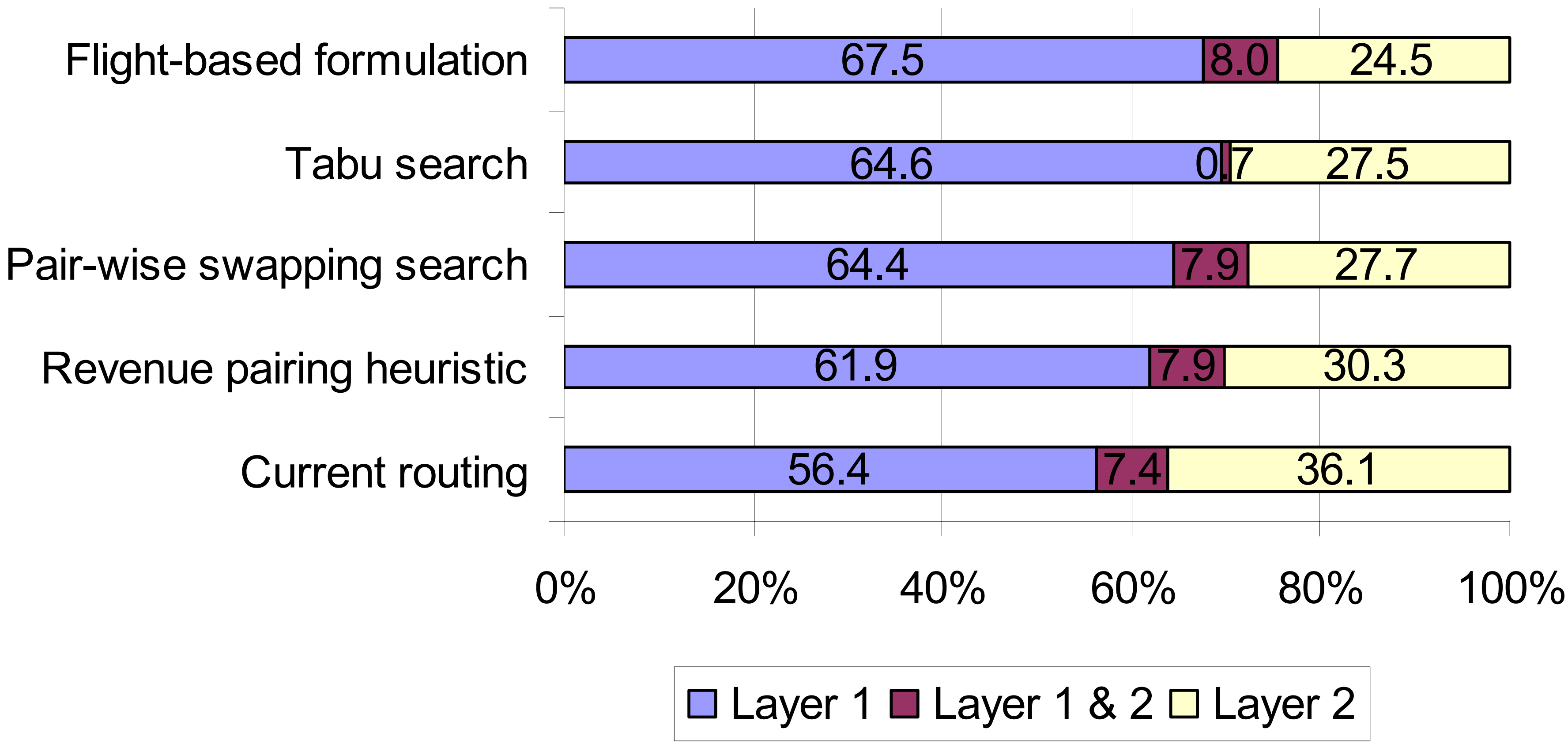
protected revenue

Flight-based Formulation	9,624,460	74.5%
Tabu search	9,057,750	70.1%
Pair-wise swapping search	9,033,010	70.0%
Revenue pairing heuristics	8,556,590	66.3%
Current routing	7,302,040	56.6%

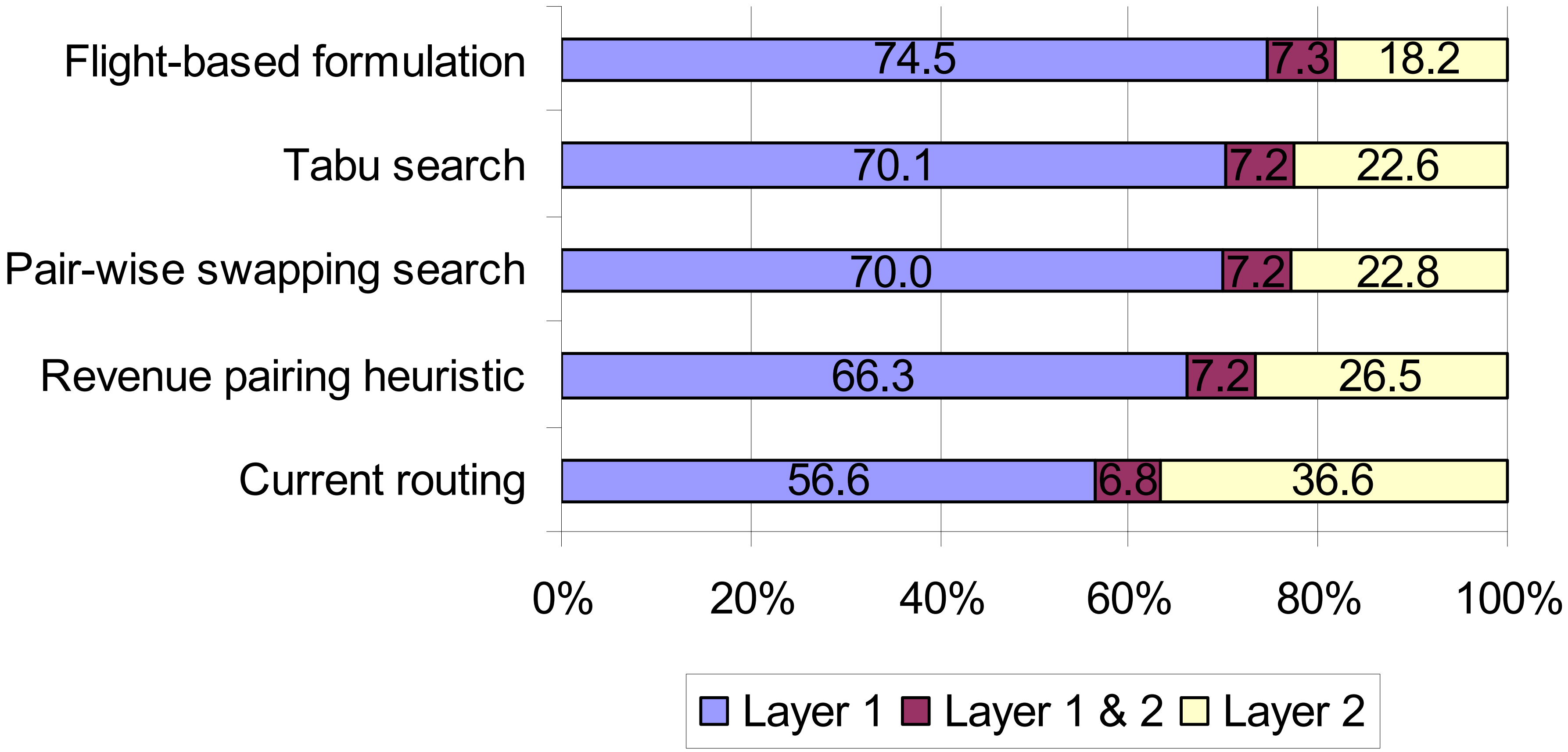
itinerary distribution



passenger distribution



revenue distribution



simulation result

- Good weather

	Layer 1	Layer 2	Current Routing
Average delay	6 min	6 min	6 min
Pr(delay >0)	0.37	0.48	0.42
Pr(delay > 15)	0.14	0.17	0.16

simulation result

- Bad weather

	Layer 1	Layer 2	Current Routing
Average delay	13 min	25 min	17 min
Pr(delay >0)	0.52	0.69	0.61
Pr(delay > 15)	0.30	0.48	0.37

summary of results

- Degradable airline schedule
  - Robust airline schedule
  - Cancellation/delay policy
  - Tool for market segmentation based on reliability
- Tabu search to solve aircraft routing
  - Within 6% of optimality gap
- Number of itinerary protected: 46.9% to 48.6%
- Revenue protected: 56.6% to 70.1%
- Difference in performance of flights in different layers is significant in bad weather

further research

- DAS with FAM
- Solve Route-based model using column generation
  - Better upper bound
  - Better lower bound
- Sensitivity analysis